CEMENT AND LIME MANUFACTURE

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Fuel Consumption of Rotary Cement Kilns.

The fuel economy drive has focussed attention on all problems of combustion, and the "fuel targets" at which industries should aim have become a common subject for discussion. It may therefore be of interest to review the relation between the theoretical heat requirements in a rotary kiln producing Portland cement clinker and the best figures which are practicable.

Rotary kilns may be operated with either a dry or wet feed (slurry). In this country the latter is now universal for reasons which will appear later. "Wet-process" kilns only are therefore considered in these notes.

Fig. 1 shows a "Sankey" diagram of the heat flow in a simple wet-process rotary kiln and cooler of high efficiency. It is essential to differentiate between

(1) Heat absorbed in effecting chemical or physical changes of state (or evolved from them), which is non-recoverable, and

(2) Heat which remains throughout the process in a sensible form and is theoretically recoverable.

The essential part of the process of producing clinker is the combination of lime with the oxides of silicon, aluminium, and iron, usually supplied in the form of clay. This combination takes place at about 2,600 deg. F. and is generally believed to be slightly exothermic. It follows, therefore, that this essential part of the process is slightly more than self-supporting. In other words, if the whole of the sensible heat used in heating the raw materials to 2,600 deg. F. could be recovered by regeneration from the hot product, then once the necessary temperature had been obtained no further fuel would be required; indeed some heat would be generated and the temperature of the material would continue to rise indefinitely. Such a state of affairs is, of course, quite impracticable for the following reasons.

First, lime is much too active a substance to occur in nature and is only available in combination—generally with carbon dioxide in the form of the carbonate

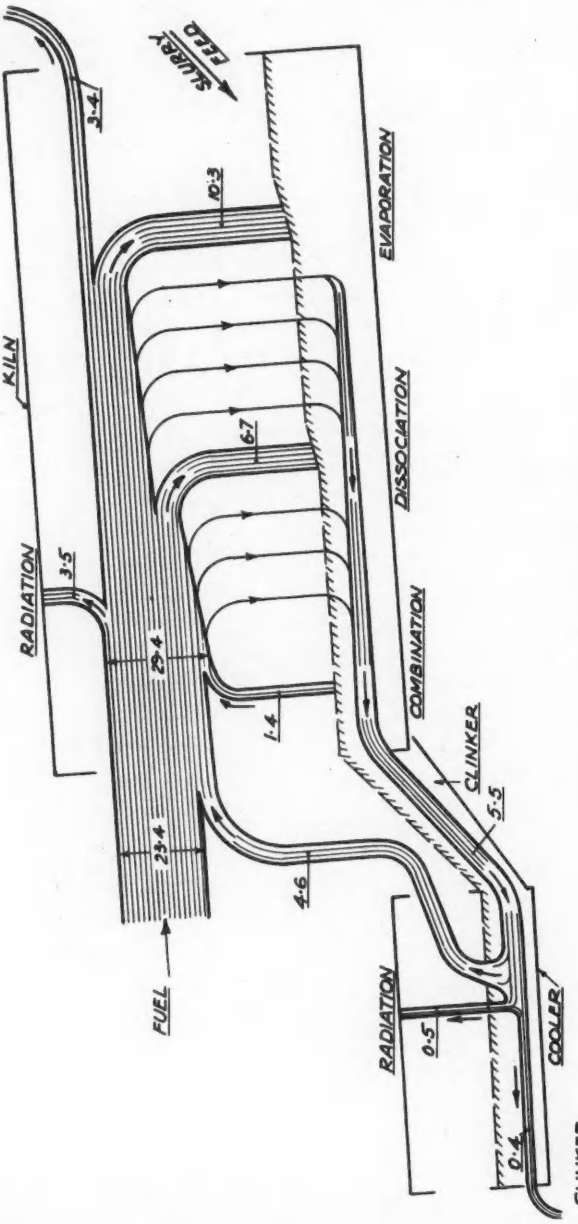

Fig. 1.—Rotary Kiln Heat Flow Diagram.

($CaCO_3$), for example, as chalk or limestone. Consequently before combination with the other oxides—which do occur as such in nature—the carbonate must be dissociated, forming lime and CO_2.

The weight of calcium carbonate required to produce one ton of clinker is about 1·20 tons and the heat required to dissociate this is about 711 B.T.U.s per lb. of carbonate; 1·20 tons, therefore, require 1·91 million B.T.U.s. This must all be supplied above about 1,650 deg. F., which is the temperature at which the CO_2 is driven off from the $CaCO_3$ and lime produced.

It is usual for the heat consumption of rotary cement kilns to be stated in terms of standard coal with a calorific value of 7,000 calories per gramme, *i.e.* 12,600 B.T.U.s per lb. or 28·2 million B.T.U.s per ton. Converted to this basis, the standard coal required for the dissociation of the calcium carbonate is 6·7 per cent. of the output of clinker. If, therefore, the mixture of raw materials, that is chalk or limestone and the oxides forming the clay, were fed to the kiln dry and all losses of sensible heat could be recovered by regeneration, the consumption would be the above figure less the small amount arising from the exothermic reaction of the combination, generally taken as a maximum about 1·4 per cent. of standard coal.

Secondly, the raw materials are never entirely dry, and in this country usually contain an average of about 20 per cent. of moisture which must be driven off. This could be done in a separate apparatus by the hot gases from the kiln itself, which would then be working with dry feed. Allowance must therefore be made for pre-drying the raw materials; this, however, is a difficult operation and its efficiency is generally low. Further, the grinding, uniform intimate mixing, and handling are more costly in the dry state than in the wet.

While, therefore, it is theoretically wrong to add to the raw materials further water which has afterwards to be evaporated, the water forms such a convenient vehicle for handling the materials that in practice the use of slurry is generally advantageous. Consequently it is the universal practice in England to mix and grind (or wash) the raw materials into slurry, the water content of which is generally about 40 per cent. This slurry, which forms the feed to the kiln, consists approximately of

Oxides (which ultimately form clinker)	40 per cent.
CO_2 in combination with the lime	20 ,,
Water	40 ,,

It follows that water equivalent in weight to the clinker produced has to be evaporated in the kiln, and this is effected by the hot gases after the pre-heating of the raw materails and the dissociation of the calcium carbonate. The CO_2 thus produced passes along the kiln with the other hot gases and gives up most of the sensible heat which it has absorbed before dissociation.

In simple rotary kilns, that is those not having separate slurry dryers, and in favourable circumstances, the evaporation of the moisture can be effected so that the temperature of the waste gases falls to about 400 deg. F., when they have little further commercial use, especially as they carry a large amount of moisture and have a dew point of about 160 deg. F. The heat required for the evaporation

of the moisture expressed as standard coal is equal to about 10·3 per cent. of the weight of clinker produced.

These figures may be summarised as follows in terms of standard coal per ton of clinker :

Dissociation of calcium carbonate	=	6·7 per cent.
Evaporation of the moisture	=	10·3 ,,
		17·0 ,,
Less exothermic reaction	=	1·4 ,,
Net heat absorbed	=	15·6 ,,

This figure, however, assumes that the whole of the sensible heat is recovered by regeneration, but this is not practicable. As already explained, the sensible heat in the waste gases from an efficient kiln is not commercially usable.

The diagram shows that the recoverable sensible heat is transferred to the materials mainly in two stages, namely, between the evaporation of the water in the slurry and the dissociation of the $CaCO_3$, and again between this and the final combination. This transference takes place continuously, and the sensible heat is carried by the clinker from the kiln into the cooler which acts as a regenerator, the heat being transferred to the air for combustion. The efficiency of regeneration is $\frac{4·6}{5·5} = 84$ per cent.

There remain the following losses of sensible heat which complete the balance :

	Per cent. of standard coal
In the waste gases, including the water vapour, at 400 deg. F.	3·4
In the clinker leaving the cooler at about 250 deg. F. ..	0·4
In radiation and other losses from the shells of the kiln and cooler	4·0
Total	7·8

A large part of the last loss takes place from the shell of the kiln in the neighbourhood of the burning zone. This is largely unavoidable because, unless a certain amount of heat-flow through the brick lining and shell is permitted, the lining will not have a useful life.

The figures may be summarised as follows :

	Per cent. of standard coal
Net heat absorbed in physical and chemical changes ..	15·6
External losses in waste gases, clinker, and radiation ..	7·8
Consumption of fuel	23·4

This may be taken as applying to a very efficient unit, and is seldom attained unless the raw materials allow of using less than 40 per cent. of water in the slurry. It may, however, be accepted as a possible target for wet-process kilns. Given

good combustion, for which the conditions in a rotary kiln are favourable, its attainment depends chiefly on securing a low temperature in the exit gases. This depends on the perfection of the arrangements for evaporating the water in the slurry. In view of the sticky nature of slurry when it is partially dry, the difficulties are considerable. In many plants there is also room for some small improvement in regeneration in the clinker cooler.

Joining Two Rotary Kilns.

IT was recently decided to start production again at an American wet process Portland cement factory which was built in 1923 but which had been inactive for ten years. Before doing so, however, the two 11-ft. 3-in. by 200-ft. kilns were joined together to make one kiln 400 ft. long. When two kilns were operated the works had a rated capacity of 500 tons of clinker per day, and the output of the single kiln is 400 tons a day. The two kilns each exhausted to a separate concrete stack at 1,200 to 1,300 deg. F. They were fired by coal from a central grinding plant by separate blowers, with a coal consumption of 690 lb. to 750 lb. per ton. Combustion air was not preheated. Each kiln was driven by a 100 h.p. electric motor and variable-speed drive. Clinker was elevated into storage by a pan conveyor and the only cooling was by water sprays.

In converting to a single-kiln plant, one 200-ft. kiln was left on its foundations with its drive in the original position. The second kiln was joined to it and the converted kiln extends outside the kiln building beyond the stacks. An A-frame hoist and temporary foundations were used to place the kiln extension and hold the shell in place while riveting the two together with a 48-in. butt strap and placing the permanent foundations

The long kiln operates under induced draft. A new feed arrangement had to be constructed and a wind tunnel of sheet steel was built from a 9-ft. draught fan to connect to the stacks. There is a common breeching at the two stacks so that the exhaust gases normally separate into both stacks. Inside the breeching, water sprays are fitted to clean the gases. The lengthened kiln is equipped with heat-exchange chains.

The kiln has a dual drive. The gear drive from the 100 h.p. motor on the kiln left in place is still in its original position, and the drive from the second short kiln has been mounted in its former position. Both drives are variable speed and are arranged so that when one is started up or stopped the second drive also starts or stops. Similarly, a change in speed of one automatically varies the other. Power consumption at one revolution every two minutes is 150 h.p.

The kiln is now direct-fired by a bowl mill and has a simplified recuperator. The clinker is now of more uniform quality and is easier to grind, and the expansion of the cement has been reduced. The coal consumption has been reduced by about 240 lb. per ton of clinker, and the temperature of the exhaust gases has been reduced from 1,300 deg. F. to 400 deg. F.

The Construction of the Rotary Kiln.

THE operating conditions of the rotary kiln are such that its parts are subjected to a wide range of temperatures as well as of loading stresses; high temperatures and temperature changes also produce stresses which are much more difficult to provide against than load stresses. These conditions all existed in the earliest kilns, but the smaller dimensions and lighter loading proved less searching as a reserve of strength was provided. A similar reserve in the present larger kilns would result in a serious increase in weight and cost; also, many factors in design react upon one another and the results become cumulative.

Early Kilns.

The shells of the earliest kilns appear to have been about 6 ft. in diameter by about 50 ft. long. They were supported on two tyres, riveted to the shell, and these in turn were supported on two pairs of anti-friction rollers. The kiln was arranged with an inclination of 1 in 24 or 1 in 25, and the downward thrust was taken care of by a single thrust roller which engaged with one edge of one of the tyres. The drive was through a girth gear, fixed to the shell, generally in line with present practice. The method of attachment of the tyre proved unsatisfactory, and several modifications were made before the floating riding ring was adopted. Firebrick lining 4½ in. thick was used, and this, in conjunction with the dimensions of the shell, resulted in an internal volume of nearly 800 cub. ft. which, under wet-process conditions, enabled the kiln to produce a maximum of 16 cwt. to 18 cwt. of clinker per hour. The coal-clinker ratio was possibly greater than 40 per cent. The temperature of the clinker discharged and of the gases was very high. Comparable figures for a modern kiln would be much lower, owing partly to the large size of the kiln, but owing more to its lower rating and the greater care exercised in its operation and control.

Modern Kilns.

Modern kilns are usually from 250 ft. to 350 ft. long, although kilns have been made more than 500 ft. long. The usual diameter is from 8 ft. or 9 ft. up to 11 ft. and sometimes larger. The shell is made parallel if the kiln is to work on the dry process or if it is operated in conjunction with a Lepol grate or a Calcinator. If, however, the kiln is to work on the normal wet process, the shell would probably have one or two enlargements (one at the slurry end and the other would become the decarbonating and combustion zone); these enlargements enable the material to remain in or at these areas for a longer time so that the processes may be more efficiently carried out. There is no need for this extended time in the dry-process kiln, nor in the Lepol or the Calcinator kilns, as the processes are much farther advanced than in the wet-process when the material enters the kiln.

The net, or effective, volume of a relatively large modern wet-process kiln may be, say, 25,000 or 30,000 cub. ft. The output would vary between, say, 10 cwt. or 12 cwt. and 18 cwt. or even 20 cwt. of clinker per hour per 1,000 cu. ft. of internal volume. Generally, high rating results in a high coal-clinker ratio; it appears almost impossible, with a plain wet-process kiln, to combine a high

output with low coal consumption, although selected fittings and equipment have done so under some or special conditions.

These large dimensions have not been approached for any kiln other than a wet-process kiln, neither is there any need for such dimensions owing to the higher output rating of other kilns; moreover, difficulties might arise in dealing with the large amount of clinker produced. The design problems would also be greater owing to the expansion due to the considerably higher shell temperature usual with such kilns.

This article considers some of the problems that may arise in the design of a wet-process kiln of considerable dimensions. For this purpose it will not matter whether the shell is parallel or if it has one or more enlargements, because the weight, loading, and the resultant stresses will have substantially the same effect whatever the form of shell.

Spacing of Rings.

Under normal conditions the shell operates as a rotating beam and is subjected to tensile and compressive stresses. The shell is also subjected to twisting or torsional stress while it is rotating, and to crushing or collapsing stress, at the points of support, owing to the method of support adopted.

The use of a floating riding ring instead of a riveted tyre for supporting the shell is now almost universal practice. The design of a tyre and its riveted attachment to the shell for supporting a load of up to, say, 150 or 200 tons bristles with difficulties, but it is now not necessary. It may, however, be pointed out that the design of the floating ring and its attachments for a load of this magnitude requires careful thought.

The centre-to-centre distance between riding rings has ranged between about 45 ft. and 70 ft., with an average of, say, 50 ft. to 60 ft., and this appears to have become the rule whatever the diameter of the shell. In only rare instances has the dimension been greater than 70 ft. Generally the rings are too closely spaced. Better proportions would result if the spacing of the rings were a factor of the diameter of the shell, for it is obvious that a ratio of that kind matters most. At present the ratio of spacing to shell diameter is from 4·5 to 6·5, with only occasional instances above or below these ratios; one example, however, came to our notice where the centre-to-centre distance was about 10 diameters of the shell.

A longer central span would enable a better distribution of weight to be obtained. If we imagine a kiln having only two supports it will be clear that there could be no error in its alignment, and the weight would be substantially divided between the two rings; it will also be clear that any increase in the number of rings (or closer spacing of the rings) will increase the difficulty in obtaining good weight distribution and in obtaining and maintaining alignment. At the usual ring spacing the bending stress in the intermediate sections of a kiln shell is normally low so long as reasonable alignment is maintained; the bending stress increases and decreases with the distance between the centres of these rings, except in the end spans.

Length of Sections.

Up to recent years all shell joints have been connected by cover-plates and rivets, but, owing to the wider experience now available, there is every reason why the sections—usually from 35 ft. to 45 ft. in length—should be connected by welding at the maker's works; this procedure would save up to 10 per cent. or 12 per cent. of the net weight of these sections, as well as labour in their construction. Until further experience is gained it appears desirable for the sections to be connected on the site by the usual cover-plate and rivet method, and this should eliminate the risk of bad jointing and ensure good alignment. The sections should be made as long as practicable for convenient handling, bearing in mind any difficulties that may exist on the site and also the spacing of the rings and the overall length of the supporting sections. The point-of-support section, complete with doubling plates, chairs, and riding ring, should be riveted together as a self-contained unit with cover-plates ready for the attachment of the welded sections. The possible heavier loading would call for closer pitching of the chairs and for the minimum diametral clearance between the chairs and riding rings; these parts would all be riveted together in agreement with present practice.

Support of Riding Rings.

The design of a kiln, having recuperator cylinders attached to the lower end, calls for the greatest care at the point of attachment and support of the lower riding ring, owing to the considerable overhanging weight, the high temperature, and the pressure exerted by the supporting rollers; it is possible that the pressure of the rollers causes or sets up the most severe conditions owing to the amount of shell distortion that results.

It is considered possible that a four-point support for the lower riding ring would meet heavy load conditions better than the two-point support, and, what is much more important, the four-point support would reduce the amount of shell distortion that is now so usual. To develop the idea in a satisfactory manner will call for a complete new design of roller bed with twin roller brackets, and also of most, if not all, the details. It is possible that owing to the lower unit loading the diameter of the replace rollers could be made smaller than at present. In any case this part of the design would require to be considered; it is understood that the lower of each pair of rollers would still carry the greater part of the total weight.

Effect of High Temperature.

Figures obtained from time to time, with the shell lining in average condition, indicate that a temperature difference between the inner surface of the riding rings and the engaging surface of the chairs varies between 100 deg. F. and 250 deg. F. If the lining is thick, the general temperature is lower and the difference less, especially at the slurry end. If the lining is thin the general temperature is higher and the difference greater, especially at the clinker end. If we assume a mean temperature difference of 200 deg. F. and the internal diameter of the ring to be 140 in., and adopt a figure of 0·000006 for the coefficient of expansion

for both surfaces, we arrive at a mean diametral difference of 0·165 in. (say $\frac{3}{16}$ in.). This mean figure might be reduced by $\frac{1}{16}$ in. at the slurry end and increased by the same amount at the clinker end. These figures represent the actual difference that exists under cold conditions, but should result in only just a working clearance under normal operating conditions. This small clearance should definitely limit the amount of distortion of the shell at the points of support and, what is much more important, it would reduce the " sloppiness " and wear at this point.

The lengthwise expansion of a kiln shell will vary with the thickness and condition of the lining. It will be greatest at the firing end and least at the slurry end. Under fair conditions the cold-to-hot expansion of the shell of a wet-process kiln may approximate 1/500 of its total length ; that is to say, a kiln 500 ft. long will expand up to 12 in. ; these figures are illustrative and typical, and must not be regarded as exact or final.

Thrust Rollers.

The total thrust on a kiln is a factor of the total revolving weight and the inclination. If the revolving weight of a kiln were, say, 1,200 tons and the inclination, say, 1 in 25, the total thrust becomes nearly 50 tons, and this must be provided for either in the thrust roller direct or by " cutting " the load rollers. Kiln operators occasionally point out, with an amount of pride, that their rollers are adjusted so that the kiln " floats " without any pressure being taken by the thrust roller, but the fact that this pressure must be exerted at some point, and that the adjustment of the load rollers has transferred the thrust pressure from the part that had been prepared to take it to a part or parts that had not been so prepared, have been overlooked. Moreover the area of the faces of the bearings that now take the thrust are much too small for the pressure. Apart from the above, a thrust pressure of about 50 tons is much too heavy to be taken by a single thrust roller, and reducing the pressure on the thrust roller by transferring a part to the load rollers is very undesirable practice owing to the lack of control, for load rollers become very sensitive when called upon to take a share of the thrust. An improvement would result if two thrust rollers were applied, one a fixed thrust and the other a floating thrust ; the floating thrust would involve a sliding pillar or equal, and the amount of thrust it would take would depend upon the weight in the load box, or equal, or as obtained by the setting up on a " gang " of springs ; the residual thrust would be taken up by, or on, the fixed roller. Dividing the thrust in this way involves careful setting of the load rollers, as the slightest irregularity on the surface of the rollers and rings results in, or sets up, a condition of creep and the kiln will soon get out of control.

Torsional Stresses.

One other point to which reference may be made is the amount of twist that takes place in the starting up, or even in the normal running, of small or medium diameter kiln shells of considerable length. Although the torsional and shear stresses may not be high, these shells tend to behave in the same way as long

shafts of small diameter, running light, when the end remote from the drive continuously lags behind and then over-runs the driving end alternately. When motion of this kind takes place the ends of the shell move in a series of steps or jumps. These cycles of movement are, or may be, a reproduction of the number of teeth in the large girth gear when driven with a pinion having a very small number of teeth, and the number of steps or cycles of movement per revolution of the kiln may be the same number, or twice, or even four times, the number of the teeth in the large gear; the actual number will depend partly upon the accuracy of tooth pitch but more upon the form of curve of the tooth face and tooth engagement. There is no real objection to this motion except that it produces a wave-like surface on the load faces of both the riding rings and the rollers; the waviness is usually most pronounced at the slurry end of the kiln, which may be the lightest loaded and most truly balanced, but it may also appear at the clinker end of some kilns.

A two-motor drive has already been considered for long shells as a cure for this condition, but so far as is known a two-motor drive has not yet been adopted. Considerable care with the principles involved, and also with the details, would be necessary to ensure against failure in any part of a design of this kind; there is nothing difficult provided all the possibilities are considered.

Standardisation of Laboratory Apparatus.

The British Laboratory Ware Association, Ltd., of 73, Basinghall Street, London, E.C.2, has formed a technical committee the objects of which are: (1) To promote closer co-operation between the designers and manufacturers of standard laboratory instruments and apparatus; (2) To assist in the design of apparatus and to eliminate overlapping with the aim of securing economical production; and (3) Collaboration with standardising authorities, research associations, etc., in the drafting of specifications.

Dust Collection.—A new publication, entitled "Sirocco Dust Fans," has been issued by Messrs. Davidson & Co., Ltd., of Belfast. This well-illustrated brochure of 44 pages describes most of the fans and dust collecting plant for which the firm is well known. Full specifications are given of a wide variety of fans suitable for cement works and other industrial undertakings where quantities of dust and gas have to be handled. Copies of the brochure will be sent to firms interested in these problems.

Effect of Additions to Portland Cement Clinker.

THE results are given in Research Paper No. 1,533 of the United States National Bureau of Standards of a study made by Messrs. G. S. Newman, R. L. Blaine, C. H. Jumper, and G. L. Kalousek, on the effect on the properties of Portland cement clinker of a number of added materials. The cements used in the tests were normal, high-early strength, moderate heat of hydration, sulphate-resistant, and white Portland cements, and the materials added (in the proportions given in brackets) were: Gypsum (3·75 per cent.), calcium chloride (1·46 per cent., anhydrous basis), calcium acetate (1·35 per cent., anhydrous basis), sugar (0·05 per cent.), tannic acid (0·20 per cent.), triethanolamine (0·10 per cent.), fluosilicic acid (0·33 per cent., anhydrous basis), and T.D.A. (0·033 per cent.). Samples containing these additions were compared with samples to which nothing had been added. It was found that although some of the additions caused large changes in the behaviour of the clinker pastes during early stages, few of them had much effect at 28 days. A summary of the results is as follows.

Temperature and Setting Time.

Gypsum reduced the initial temperatures of the pastes as well as the temperatures attained during the first three hours. The maximum temperatures, however, were increased frequently by rather large amounts, and the times required to reach the maximum temperatures were reduced in many instances. The lower temperatures attained during the first three hours were accompanied by increases in the fluidities of many of the pastes. Increased flows were observed for the concretes made from many of the clinkers. Certain of the clinkers exhibited quick-setting, which was eliminated by the addition of gypsum.

Sugar increased the temperatures attained in 15 minutes by nearly all the clinkers, but for many of the clinkers it also increased the time required to reach the maximum temperatures. The quick-setting which some of the clinkers exhibited was retained, and this was caused in one case when sugar was added. Sugar also increased the flows of the majority of the concretes.

Calcium chloride caused a decrease in the initial temperatures of seven of the clinker pastes and an increase in the initial temperatures of the remainder. Shortly thereafter, however, the temperatures increased rapidly, and at the end of three hours the temperatures of the pastes containing calcium chloride were from 5 deg. to 50 deg. C. higher than those of the clinker pastes alone. Calcium chloride eliminated the quick-setting exhibited by five of the clinkers. The flows at half an hour were increased for nearly all of the clinkers, but at two and a-half hours the flows were increased for only four of the clinkers and decreased for all but one of the remainder.

TDA increased the temperatures attained at 15 minutes for nearly all the clinkers. With a few exceptions, the maximum temperatures of the pastes containing TDA were equal to or only slightly greater than the temperatures attained by the clinker pastes containing no added material. For the majority

of the clinkers the times required to reach the maximum temperatures were only slightly changed. TDA eliminated quick-setting and reduced the stiffening of the pastes in most instances. The flows of concretes containing TDA gave the highest averages both at half an hour and two and a half hours. With the exception of the effects on the time-temperature curves, many of these changes may have been caused, at least in part, by prehydration, since the TDA was added to the ground clinkers as an aqueous solution 24 hours before the tests were begun.

Tannic acid increased the temperatures attained in 15 minutes by all but four of the pastes. The maximum temperatures were increased for only three of the clinkers and were decreased or unchanged for the remainder. The times required to reach the maximum temperatures were increased. All but three of the clinker pastes stiffened more rapidly when tannic acid was used. The majority of the flows were affected only slightly or not at all.

Triethanolamine increased markedly the temperatures reached in 15 minutes and also increased the maximum temperatures attained. The times required to reach the maximum temperatures were decreased for six of the clinkers and changed only slightly or increased for the remainder. Ten of the clinkers showed quick-setting. The flows of nearly all the concretes were decreased. Two of the clinkers showed little change in the stiffness of the pastes and in the flows of the concretes. In some instances, the flows could not be determined when triethanolamine was added.

Calcium acetate either increased or decreased by a small amount the temperatures attained by the pastes at 15 minutes. The times required to reach the maximum temperatures were increased. Calcium acetate eliminated the quick-setting exhibited by five of the pastes. In many cases the pastes became very sticky. The flows of the concretes made from six of the clinkers were decreased, whereas the remainder were either increased or not greatly affected.

Fluosilicic acid increased the temperatures attained at 15 minutes for nearly all the clinkers. The maximum temperatures were decreased for a majority of the clinker pastes, and the times required to reach the maximum temperatures were increased. Quick-setting was retained and, in two instances, was caused by fluosilicic acid. The flows of the concretes made from five of the clinkers were decreased, whereas the remainder were affected only slightly or not at all.

Heat of Hydration.

Gypsum increased the heats of hydration at half a day, sometimes by several hundred per cent. At one day, two-thirds of the heats of hydration were increased by an average of 30 per cent. The changes at seven days were small, whereas at 28 days most of the heats of hydration were unchanged.

Sugar reduced the heats of hydration of half of the clinkers at half a day by an average of 48 per cent. On the other hand, three heats of hydration were increased by nearly the same amount. At one day one-third of the heats of hydration were decreased by an average of 47 per cent. and one-third were increased by about half as much. At seven and 28 days a few more increases than decreases in the heats of hydration occurred, but the changes were small.

Calcium chloride increased the heats of hydration at half a day, usually by even larger amounts than did gypsum. At one day, three-fourths of the heats of hydration were increased and none was decreased. At seven days the increases were more frequent and somewhat larger than the decreases, whereas at 28 days half of the heats of hydration were decreased by calcium chloride by an average of 8 per cent.

TDA tended to increase the heats of hydration at early ages and to leave them unchanged or to decrease them later. With a few exceptions the changes were not large.

Tannic acid reduced nearly all the heats of hydration at half and one day, whereas at seven and 28 days most of the heats were unchanged or increased. The decreases were frequently rather large, whereas the increases seldom exceeded 25 per cent.

Triethanolamine increased most of the heats of hydration at all ages for which data were available. In several instances pastes containing triethanolamine hardened so rapidly that all tests were not performed. The few decreases in the heats of hydration that occurred were usually rather large.

Calcium acetate and fluosilicic acid decreased the majority of the heats of hydration at half and one day and increased them at seven and 28 days. In general, the decreases were larger than the increases. The effects of these substances were frequently large and variable during the first 24 hours, but by seven days most of the changes were small. At the end of 28 days very many of the heats of hydration were not affected significantly.

Gypsum and calcium chloride increased nearly all the strengths, both tensile and compressive, sometimes by several hundred per cent. at the early ages. The increases caused by calcium chloride were usually larger than those caused by gypsum.

Sugar reduced nearly all the one day strengths to zero. At seven and 28 days many of the strengths were increased. Notwithstanding the fact that sugar is generally considered harmful, it is apparent that in the amounts added in these tests it did not reduce the strengths developed by the clinker pastes after the first few days.

TDA (together with the water in which it was dissolved, 0·23 per cent. by weight of the clinker) reduced to zero the one-day strengths of two of the clinkers. A few of the strengths at one day were increased, but the majority were either unchanged or reduced by TDA. At seven and 28 days the tendency of TDA was, with a few exceptions, to change the strengths by only small amounts.

Tannic acid reduced nearly all the one day strengths to zero. At three days many of the strengths were decreased and only a few were increased. At seven and 28 days in the majority of cases tannic acid had little effect on the strengths.

Calcium acetate reduced the one day strengths of a majority of the clinkers. In five cases the strengths were reduced to zero. However, in a few cases rather large increases in the one day strengths were caused by calcium acetate. At

the later ages, calcium acetate increased the strengths of a majority of the clinker pastes.

Fluosilicic acid reduced nearly all the one day strengths to zero. At three days most of the strengths were reduced, but at seven and 28 days the strengths were unchanged or slightly increased.

Sugar Solubility.

The highest permissible "clear point" a cement may show and pass the Merriman test is 10 ml. of 0·5 *N* HCl. Only three clinkers were below this limit. Gypsum lowered all the clear points sufficiently for three clinkers having high clear points to be included in the group below 10 ml. of 0·5 *N* HCl. Calcium chloride increased the clear points of many of the clinkers, whereas TDA affected them only slightly. Tannic acid decreased nearly all the clear points by rather large amounts in some cases, and brought two clinkers having high clear points into the group having clear points of less than 10 ml. of 0·5 *N* HCl. Triethanolamine increased most of the clear points but decreased a few, in one case sufficiently to include the clinker in the group passing the test for cement. Calcium acetate slightly increased the majority of the clear points. Fluosilicic acid lowered all the clear points sufficiently for six clinkers with high clear points to include them in the group having clear points of less than 10 ml. of 0·5 *N* HCl.

[A report of an investigation on the effect of similar additions on aqueous extracts of Portland cement clinker pastes was given in the June number of this journal.]

Effect of Calcium Chloride on Portland Cement.

A SERIES of tests has been made at the Building Research Station on the effects of the addition of calcium chloride to Portland cement and concrete. Ordinary and rapid-hardening Portland cements were used, and the concrete specimens were made with 1 : 2 : 4 mixtures of cement, sand, and gravel with a water-cement ratio of 0·60. Granulated calcium chloride containing 90 per cent. $CaCl_2$ and flake calcium chloride containing 74 per cent. $CaCl_2$ were used in various proportions. The tests were made to ascertain the effects of calcium chloride at normal temperatures on the setting of cements; the rate of strength development of concrete during early stages and over longer periods; workability of

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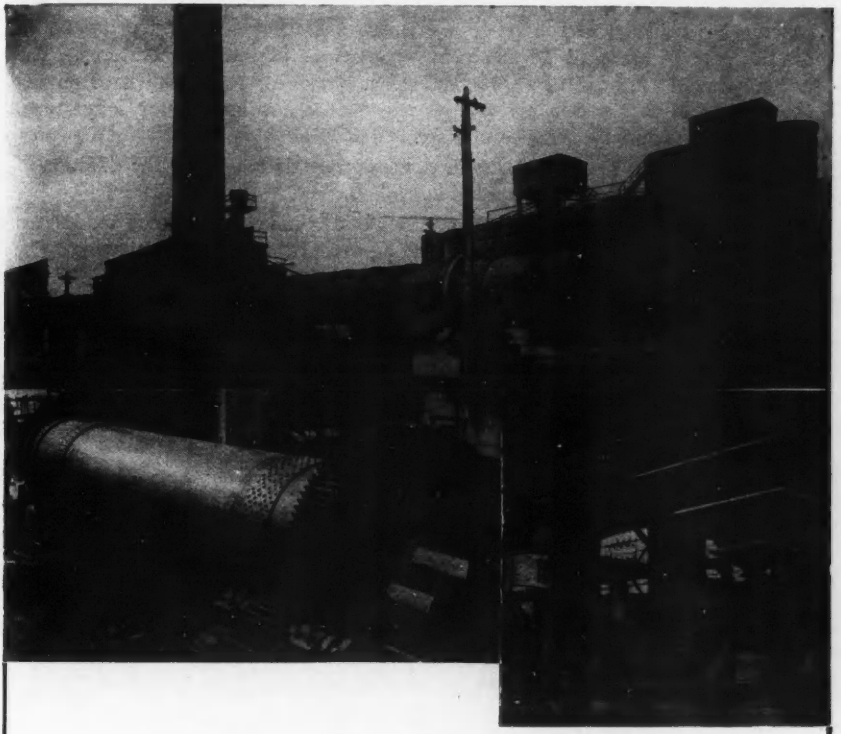
Advertisements must reach this office by the 5th of the month of publication.

RESEARCH WORK.

Seeking contact with firm or individual prepared to back ideas in (a) concrete, (b) rapid transport. Research facilities and nom. salary required for one year. Gerard K. Cooper, "Norfolk Reeds," 36, Derby Road, Beeston, Notts.



CEMENT MAKING MACHINERY

The whole resources of this Company being entirely devoted to production for national purposes, it is not possible to quote for delivery abroad until normal conditions return.

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concrete; shrinkage of concrete; corrosion of steel reinforcement; and also on the rate of strength development of concrete at low temperatures. The investigation is fully reported by Mr. A. J. Newman, B.Sc. (of the Building Research Station) in *Concrete and Constructional Engineering* for May, 1943. The author's summary of the results are as follows:

(1) The setting times of Portland cements were decreased by the addition of increasing amounts of calcium chloride.

(2) At normal temperatures, the addition of calcium chloride much accelerated the rate of strength development at early ages, and this enables shuttering to be removed earlier, the speed of concrete working being thereby increased.

(3) Additions of calcium chloride improved the strength of air-stored concrete at all ages up to 90 days. At normal temperatures and for ages exceeding three days additions of more than 2 per cent. of calcium chloride did not cause any appreciable further increase in strength.

(4) The workability of concrete was increased by the addition of commercial calcium chloride up to and including 4 per cent.

(5) The shrinkage of concrete was increased by additions of calcium chloride.

(6) The addition of 2 per cent. of calcium chloride appears to cause a slight initial corrosion of steel reinforcement, but the evidence available indicates that this does not progress with age.

(7) Additions of calcium chloride increased the strength of concrete stored at low temperatures. At temperatures which do not fall below freezing-point, the addition of calcium chloride accelerates the rate of development of strength considerably, and is therefore of value in cold weather construction in decreasing the time necessary for protecting concrete. For temperatures which are continuously below freezing-point and where the concrete is liable to become frozen, the addition of calcium chloride should not be relied upon solely to give adequate protection against damage by frost.